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Measurements of the $t\bar{t}$ charge asymmetry using the dilepton decay channel in pp collisions at $\sqrt{s} = 7$ TeV

CMS Collaboration ; Canelli, M F ; Chiochia, V ; Kilminster, B ; Robmann, P ; et al

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Measurements of the $t\bar{t}$ charge asymmetry using the dilepton decay channel in pp collisions at $\sqrt{s} = 7$ TeV



The CMS collaboration

E-mail: cms-publication-committee-chair@cern.ch

ABSTRACT: The $t\bar{t}$ charge asymmetry in proton-proton collisions at $\sqrt{s} = 7$ TeV is measured using the dilepton decay channel (ee , $e\mu$, or $\mu\mu$). The data correspond to a total integrated luminosity of 5.0 fb^{-1} , collected by the CMS experiment at the LHC. The $t\bar{t}$ and lepton charge asymmetries, defined as the differences in absolute values of the rapidities between the reconstructed top quarks and antiquarks and of the pseudorapidities between the positive and negative leptons, respectively, are measured to be $A_C = -0.010 \pm 0.017$ (stat.) ± 0.008 (syst.) and $A_C^{\text{lep}} = 0.009 \pm 0.010$ (stat.) ± 0.006 (syst.). The lepton charge asymmetry is also measured as a function of the invariant mass, rapidity, and transverse momentum of the $t\bar{t}$ system. All measurements are consistent with the expectations of the standard model.

KEYWORDS: Hadron-Hadron Scattering, Top physics

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1 Introduction

Among the standard model (SM) fermions, the top quark is distinguished by its large mass. In several theories of physics beyond the SM, new phenomena are predicted through interactions involving top quarks. Measuring the properties of top quarks is therefore important not only for checking the validity of the SM, but also as a key probe of possible new physics. Recent measurements of the $t\bar{t}$ forward-backward production asymmetry (A_{fb}) from the D0 [1] and CDF [2] experiments at the Tevatron indicate possible disagreement with SM expectations, particularly at large $t\bar{t}$ invariant mass.

Unlike the Tevatron proton-antiproton collider, the Large Hadron Collider (LHC) is a proton-proton collider, which lacks a natural definition for the charge asymmetry given the symmetric nature of the incoming protons. However, the parton distributions inside the protons are not symmetric for quarks (mainly valence quarks) and antiquarks (all sea quarks), meaning quarks (q) usually carry more momentum than antiquarks (\bar{q}). For a positive (negative) charge asymmetry in $q\bar{q} \rightarrow t\bar{t}$ events, the top quark (top antiquark) is more likely to be produced in the direction of the incoming quark in the $t\bar{t}$ rest frame, resulting in a broader (narrower) rapidity distribution of top quarks than of top antiquarks in the laboratory frame. The difference in the absolute values of the rapidities (y) of the

top quarks and antiquarks, $\Delta|y_t| = |y_t| - |y_{\bar{t}}|$, is therefore a suitable observable to measure the $t\bar{t}$ charge asymmetry A_C , defined as

$$A_C = \frac{N(\Delta|y_t| > 0) - N(\Delta|y_t| < 0)}{N(\Delta|y_t| > 0) + N(\Delta|y_t| < 0)}.$$

A similar observable [3] involving the difference in the absolute values of the pseudorapidities (η , to be defined in the next section) of the positive and negative leptons in dileptonic $t\bar{t}$ events, $\Delta|\eta_\ell| = |\eta_{\ell+}| - |\eta_{\ell-}|$, is used to define the lepton charge asymmetry:

$$A_C^{\text{lep}} = \frac{N(\Delta|\eta_\ell| > 0) - N(\Delta|\eta_\ell| < 0)}{N(\Delta|\eta_\ell| > 0) + N(\Delta|\eta_\ell| < 0)}.$$

In the SM, a small positive charge asymmetry arises from corrections to the tree-level $q\bar{q} \rightarrow t\bar{t}$ process, as explained in detail in ref. [4]. There are models of new physics that predict larger values of A_{fb} than expected in the SM from the interference of SM $t\bar{t}$ production with contributions from processes such as s -channel axigluon or t -channel W' or Z' exchange [3]. Such theories predict values of A_C and A_C^{lep} over a large range [3], and accurate measurements of these quantities can therefore provide important constraints.

This paper presents the first measurements of A_C and A_C^{lep} in the dilepton final state, using data from pp collisions at $\sqrt{s} = 7$ TeV, corresponding to an integrated luminosity of 5.0 fb^{-1} recorded by the Compact Muon Solenoid (CMS) experiment at the LHC. Previously, using a single-lepton $t\bar{t}$ event sample, CMS determined $A_C = 0.004 \pm 0.010$ (stat.) ± 0.011 (syst.) [5], while the ATLAS Collaboration measured $A_C = 0.006 \pm 0.010$ (total) [6, 7], both consistent with the SM prediction of $A_C = 0.0123 \pm 0.0005$ [4].

The analysis described in this paper uses a complementary data sample to that used in ref. [5]. The $t\bar{t}$ dilepton decay channel has a smaller background than the single-lepton channel and different systematic uncertainties. Furthermore, the dilepton channel allows us to measure the lepton charge asymmetry A_C^{lep} for the first time. The SM prediction for A_C^{lep} is 0.0070 ± 0.0003 [4]. We also measure A_C^{lep} differentially as a function of three variables describing the $t\bar{t}$ system in the laboratory frame: its invariant mass ($M_{t\bar{t}}$), rapidity ($|y_{t\bar{t}}|$), and transverse momentum ($p_T^{t\bar{t}}$). Since the reconstructed asymmetries are distorted by detector effects, we apply an unfolding technique to determine the parton-level distributions, which can be directly compared with theoretical predictions.

2 CMS detector

The central feature of the CMS apparatus is a superconducting solenoid, 13 m in length and 6 m in diameter, which provides an axial magnetic field of 3.8 T. The bore of the solenoid is equipped with a variety of particle detection systems. Charged-particle trajectories are measured with a silicon pixel and strip tracker, covering $0 \leq \phi < 2\pi$ in azimuth and the pseudorapidity region $|\eta| < 2.5$, where $\eta = -\ln[\tan\theta/2]$ with θ the polar angle of the trajectory of the particle with respect to the anticlockwise-beam direction. A crystal electromagnetic calorimeter and a brass/scintillator hadron calorimeter surround the silicon tracking volume and provide high-resolution measurements of energy used to reconstruct

electrons, photons, and jets. Muons are measured in gas-ionisation detectors embedded in the steel flux return yoke of the solenoid. The detector is nearly hermetic, thereby providing reliable measurements of momentum imbalance in the plane transverse to the beams. A trigger system selects the most interesting collisions for analysis. A more detailed description of the CMS detector is given in ref. [8].

3 Event samples, reconstruction, and selection

Events are selected using triggers that require the presence of at least two leptons (electrons or muons) with transverse momentum (p_T) requirements of ≥ 17 GeV for the highest- p_T lepton and ≥ 8 GeV for the second-highest- p_T lepton. Electron candidates [9] are reconstructed by associating tracks from the silicon tracker with energy clusters in the electromagnetic calorimeter. Muon candidates [10] are reconstructed by combining information from the muon detector with tracks reconstructed in the silicon tracker. Additional lepton identification criteria are applied to both lepton flavours in order to reject hadronic jets misreconstructed as leptons [9, 10]. Both electrons and muons are required to be isolated from other activity in the event. This is achieved by imposing a maximum value of 0.15 on the relative isolation of the leptons. This is defined as the scalar sum of all additional silicon track p_T and calorimeter transverse energy (energy deposits projected onto the plane transverse to the beam) within a cone of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.3$ around the lepton candidate direction, divided by the lepton candidate p_T [11]. Here, $\Delta\eta$ and $\Delta\phi$ are the differences in pseudorapidity and azimuthal angle between the lepton candidate and the additional track or calorimeter energy deposit.

Selections are applied to reject events other than from $t\bar{t}$ production in the dilepton final state. Events are required to contain two isolated leptons of opposite electric charge (e^+e^- , $e^\pm\mu^\mp$, or $\mu^+\mu^-$). The electrons and muons are required to have $p_T > 20$ GeV and $|\eta| < 2.5$ and 2.4 , respectively. The two reconstructed lepton trajectories must be consistent with originating from a common interaction vertex. Events with an e^+e^- or $\mu^+\mu^-$ pair having an invariant mass in the Z-boson mass “window” (between 76 and 106 GeV) or below 20 GeV are removed to suppress Drell-Yan ($Z/\gamma^* + \text{jets}$) and heavy-quarkonium resonance production. The jets and the transverse momentum imbalance in each event are reconstructed using a particle-flow technique [12]. The anti- k_T clustering algorithm [13] with a distance parameter of 0.5 is used for jet clustering. Corrections are applied to the energies of the reconstructed jets, based on the results of simulations and studies using exclusive dijet and $\gamma + \text{jets}$ data [14]. At least two jets with $p_T > 30$ GeV and $|\eta| < 2.5$, separated by $\Delta R > 0.4$ from the leptons that pass the analysis selection, are required in each event. At least one of these jets must be consistent with the decay of a heavy-flavour hadron (a “b jet”), identified by the Combined Secondary Vertex b-tagging algorithm [15]. This algorithm is based on the reconstruction of a secondary decay vertex, and an operating point is chosen that gives a b-tagging efficiency of about 70% (depending on jet p_T and η) with misidentification probabilities of approximately 1.5% and 20% for jets originating from light partons (u, d, and s quarks, and gluons) and c quarks, respectively. The missing transverse energy in an event, E_T^{miss} , is defined as the

magnitude of the transverse momentum imbalance, which is the negative of the vector sum of the p_T of all reconstructed particles. The E_T^{miss} value is required to exceed 40 GeV in events with same-flavour leptons in order to further suppress the Drell-Yan background. There is no E_T^{miss} requirement for $e^\pm\mu^\mp$ events.

Simulated $t\bar{t}$ events are generated using the MC@NLO 3.41 [16] Monte Carlo generator, with a top-quark mass of $m_t = 172.5$ GeV, and the parton showering and fragmentation performed using HERWIG 6.520 [17]. Simulations with different values of m_t and factorisation and renormalisation scales are used to evaluate the associated systematic uncertainties. Background samples of $W + \text{jets}$, Drell-Yan, diboson (WW, WZ, and ZZ), and single-top-quark events are generated with MADGRAPH [18] or POWHEG [19–21], and the parton showering and fragmentation is done using PYTHIA6.4.22 [22]. Next-to-leading-order (NLO) or next-to-next-to-leading-order cross sections are used to normalise the background samples [23–30].

For both signal and background events, additional pp interactions in the same or nearby bunch crossings (“pileup”) are simulated with PYTHIA and superimposed on the hard collisions, using a pileup multiplicity distribution that reflects the luminosity profile of the analysed data. The CMS detector response is simulated using a GEANT4-based model [31]. The simulated events are reconstructed and analysed with the same software used to process the data.

The trigger efficiency for dilepton events that satisfy the selection criteria is determined using a tag-and-probe method [32]. The efficiencies for the ee , $e\mu$, and $\mu\mu$ channels are approximately 100%, 95%, and 90%, respectively, each with an uncertainty of about 2% [33]. These efficiencies are used to weight the simulated events to account for the trigger requirement. The lepton selection efficiencies (reconstruction, identification, and isolation) are consistent between data and simulation [32, 34]. To account for the differences between b-tagging efficiencies measured in data and simulation [15], data-to-simulation scale factors are applied for each jet in simulated events. Previous CMS studies [35] have shown that the p_T distribution of the top quark in data is softer than in the NLO simulation. Reweighting the top-quark p_T spectrum in the simulation to match the data improves the modelling of the lepton and jet p_T distributions, and is applied to the MC@NLO $t\bar{t}$ sample.

4 Background estimation

The backgrounds from events with a jet misidentified as a lepton and from Drell-Yan production are estimated using both data- and simulation-based techniques. The results agree within their uncertainties. The simulation is chosen as the method to predict the yields and distributions of the backgrounds, with systematic uncertainties based on a comparison with the data-based estimates. Contributions to the background from single-top-quark and diboson events are estimated from simulation alone. Recent measurements from the CMS Collaboration [36, 37] indicate agreement between the predicted and measured cross sections for these processes.

The background with at least one misidentified lepton (non-dileptonic $t\bar{t}$, $W + \text{jets}$, and multijet events) is estimated from data using a p_T - and η -dependent parameterisation of the

Sample	ee	$\mu\mu$	$e\mu$	All
$t\bar{t}$ (non-dileptonic)	38.3 ± 1.6	4.02 ± 0.45	91.7 ± 2.4	134.0 ± 2.9
W + jets	<2.0	4.7 ± 3.3	11.1 ± 5.1	15.8 ± 6.1
Drell-Yan	30.2 ± 4.4	29.6 ± 4.1	35.0 ± 4.5	94.8 ± 7.5
Diboson	8.27 ± 0.44	10.20 ± 0.47	27.90 ± 0.81	46.4 ± 1.0
Single top-quark	72.5 ± 2.1	86.8 ± 2.2	289.4 ± 4.2	448.7 ± 5.2
Total (background)	149.3 ± 5.5	135.3 ± 5.8	455.1 ± 8.4	740 ± 11
Data	1631	1964	6229	9824

Table 1. The predicted background and observed event yields after applying the event selection criteria and normalisation described in the text. Uncertainties are statistical only.

probability for a jet to be misidentified as a lepton, determined using events collected with jet triggers of different energy thresholds [38]. For both the electron and muon candidates described in section 3, an associated “loose” lepton candidate is defined based on relaxed isolation requirements [38]. The lepton misidentification probabilities are then applied as weights to events containing one lepton candidate passing the signal selection and one or more loose lepton candidates.

The Drell-Yan background outside the Z-boson mass window is estimated using the ratio of the numbers of simulated events inside and outside the window to scale the observed event yield inside the window [11]. Contributions to this region from other processes, in which the two leptons do not arise from Z-boson decay, are estimated from the number of $e\mu$ events in data and subtracted prior to performing the rescaling.

5 Event yields and measurements at the reconstruction level

The expected background and observed event yields per lepton flavour combination in the final sample are listed in table 1. The total predicted yield in the $e\mu$ channel is significantly larger than for the same-flavour channels, for which the additional requirements on the E_T^{miss} and invariant-mass of the lepton pair described in section 3 are applied to suppress Drell-Yan background. After subtraction of the predicted background yields, the remaining yield in data is assumed to be signal from dileptonic $t\bar{t}$ decays, including τ leptons that decay leptonically. All other $t\bar{t}$ decay modes are treated as background and are included in the non-dileptonic $t\bar{t}$ category. The largest background comes from single-top-quark production. The systematic uncertainties in the simulated yields are discussed in section 7.

The measurement of the $t\bar{t}$ charge asymmetry using $\Delta|y_t|$ requires the reconstruction of the entire $t\bar{t}$ event. Each signal event contains two neutrinos, and there is also an ambiguity in combining the b jets with the leptons, resulting in up to 8 possible solutions for the $t\bar{t}$ system. The Analytical Matrix Weighting Technique (AMWT) [11] is used to find the most probable solution for a top-quark mass of 172.5 GeV. In events with only one b tag, the second b jet is assumed to be the untagged jet with the largest p_T . Solutions are assigned a weight based on the probability of observing the given configuration [11],

$\Delta y_t $	$[-\infty, -0.7]$	$[-0.7, -0.3]$	$[-0.3, 0.0]$	$[0.0, 0.3]$	$[0.3, 0.7]$	$[0.7, \infty]$
$\Delta \eta_\ell $	$[-\infty, -0.8]$	$[-0.8, -0.4]$	$[-0.4, 0.0]$	$[0.0, 0.4]$	$[0.4, 0.8]$	$[0.8, \infty]$

Table 2. Binning used in the distributions of $\Delta|y_t|$ and $\Delta|\eta_\ell|$.

and the $t\bar{t}$ kinematic quantities are taken from the solution with the largest weight. To reduce the fraction of events with no analytic solution, caused largely by the presence of mismeasured jets, the E_T^{miss} and the energies and directions of the jets are allowed to vary within their uncertainties via a Monte Carlo integration over parameterised jet and E_T^{miss} resolution functions [14]. Despite this step, $\approx 14\%$ of the events still provide no solutions, both for data and simulation. In the measurement of $\Delta|y_t|$, $M_{t\bar{t}}$, $|y_{t\bar{t}}|$, and $p_T^{t\bar{t}}$, these events are not used, which is accounted for as an additional event selection requirement.

A comparison between data and simulation for the $M_{t\bar{t}}$, $\Delta|y_t|$, and $\Delta|\eta_\ell|$ distributions is shown in figure 1, where the signal yield from the simulation has been normalised to the number of background-subtracted signal events in data. The distributions from data and simulation agree in all cases. The uncorrected value of A_C at the reconstruction level is -0.005 ± 0.011 in data and 0.003 ± 0.003 in simulation, where the uncertainties are statistical only. For A_C^{lep} , the uncorrected values are 0.007 ± 0.010 and 0.002 ± 0.003 in data and simulation, respectively.

6 Unfolding the distributions

The observed $\Delta|y_t|$ and $\Delta|\eta_\ell|$ distributions are distorted relative to the true underlying distributions by the acceptance of the detector, the efficiency of the trigger and event selection, and the finite resolution of the kinematic quantities. To correct the data for these effects, we apply an unfolding procedure that yields the corrected $\Delta|y_t|$ and $\Delta|\eta_\ell|$ distributions at the parton level. These distributions represent the differential cross sections in $\Delta|y_t|$ and $\Delta|\eta_\ell|$, and are normalised to unit area.

The choice of binning for each distribution is motivated by the desire to minimise bin-to-bin statistical fluctuations. The bin sizes are chosen so that there are similar numbers of events in each bin, and are summarised in table 2.

The background-subtracted distribution \vec{b} for either $\Delta|y_t|$ or $\Delta|\eta_\ell|$ is related to the underlying parton-level distribution \vec{x} through the equation $\vec{b} = SA\vec{x}$, where A is a diagonal matrix describing the fraction (acceptance times efficiency) of all produced signal events that are expected to be selected in each of the measured bins, and S is a non-diagonal “smearing” matrix describing the migration of events between bins caused by the detector resolution and reconstruction techniques. The A and S matrices are modelled using simulated MC@NLO $t\bar{t}$ events, and the results are displayed in figures 2 and 3. The smearing in $\Delta|y_t|$ can be large in some events because of the uncertainties in the reconstruction of the $t\bar{t}$ kinematic quantities. However, the largest numbers of events in the left plot of figure 3 lie close to the diagonal, meaning there is little migration between bins that are far apart. The corresponding smearing matrix for $\Delta|\eta_\ell|$, shown in the right plot of figure 3, is close to diagonal because of the excellent angular resolution of the lepton measurements.

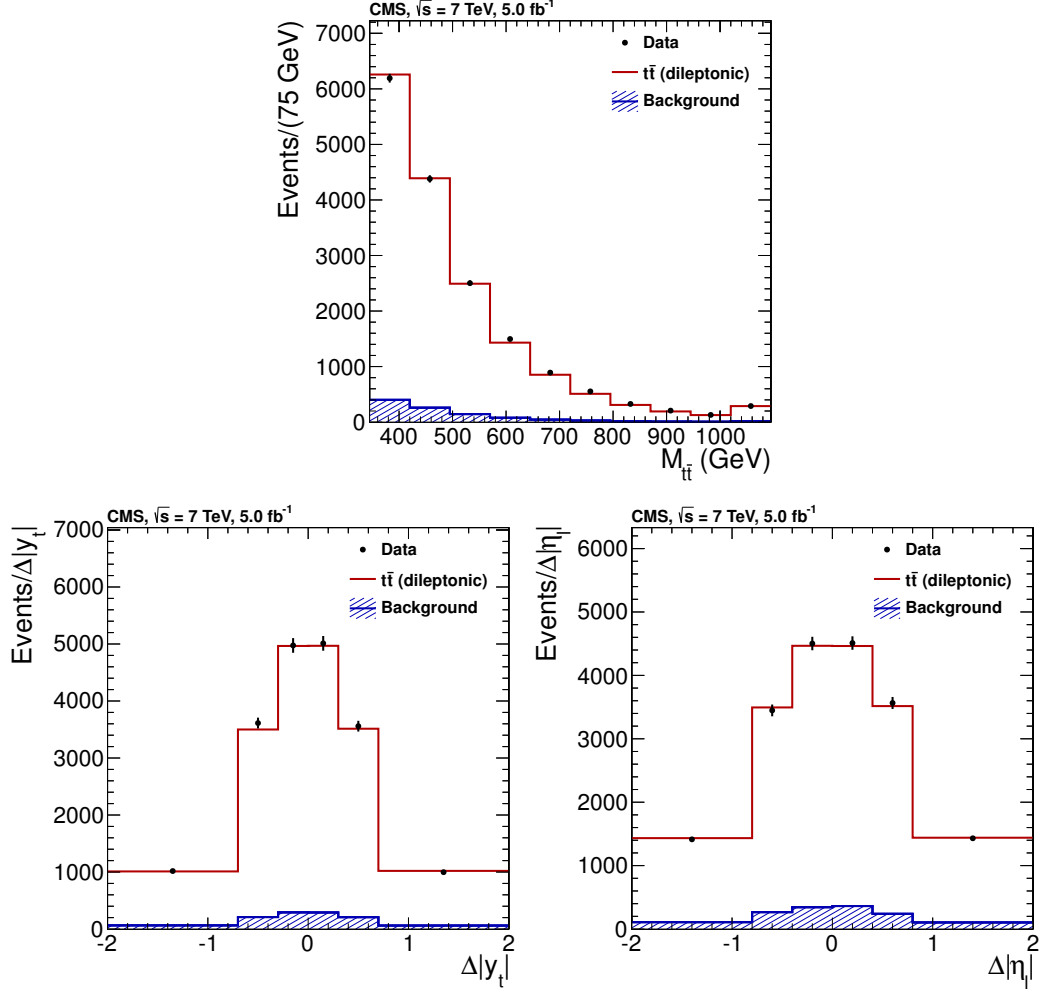


Figure 1. The reconstructed $M_{t\bar{t}}$ (top), $\Delta|y_t|$ (bottom left), and $\Delta|\eta_\ell|$ (bottom right) distributions from data (points) and simulation (histogram). The simulated events are divided into signal (open histogram) and background (dashed histogram) contributions, where the background contribution includes all event categories stipulated in table 1. The signal yield is normalised to the background-subtracted data. The first and last bins include underflow and overflow events, respectively. The error bars on the data points represent the statistical uncertainties only.

To determine the parton-level distributions for $\Delta|y_t|$ and $\Delta|\eta_\ell|$, we employ a regularised unfolding algorithm based on singular-value decomposition (SVD) [39]. The effects of large statistical fluctuations in the algorithm are greatly reduced by introducing a regularisation term in the unfolding procedure. The full covariance matrix is used in the evaluation of the statistical uncertainty in the measured asymmetry.

To verify that the unfolding procedure correctly unfolds distributions for different values of the asymmetry, we reweight simulated $t\bar{t}$ events according to a linear function of $\Delta|y_t|$ (or $\Delta|\eta_\ell|$), defined by a weight $w = 1 + K\Delta|y_t|$ (or $\Delta|\eta_\ell|$). The parameter K is varied between -0.3 and 0.3 in steps of 0.1 , introducing asymmetries between approximately -0.2 and 0.2 (far beyond the SM expectations). For each value of K , we generate a set of pseudoexperiments in which the number of events in each bin of the measured

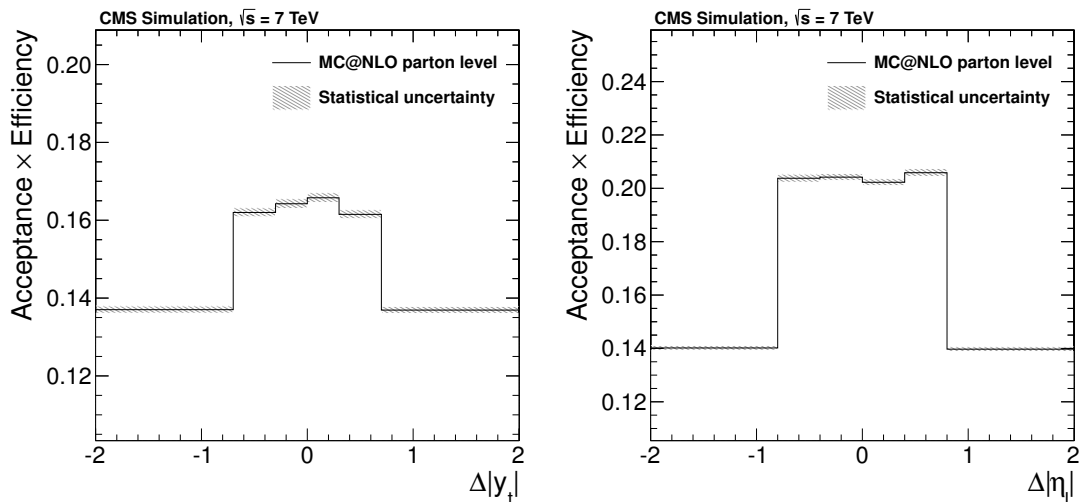


Figure 2. Diagonal elements of the matrix A describing the acceptance times efficiency of signal events as a function of $\Delta|y_t|$ (left) and $\Delta|\eta_\ell|$ (right) from simulated MC@NLO $t\bar{t}$ events. The statistical uncertainties are represented by the hatched band, and the first and last bins include underflow and overflow events, respectively.

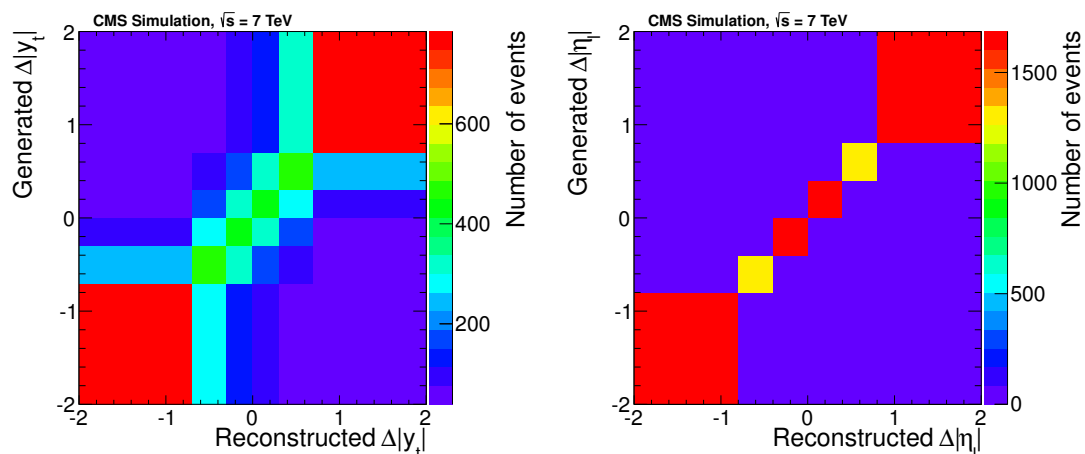


Figure 3. Binned distributions of generated versus reconstructed values of $\Delta|y_t|$ (left) and $\Delta|\eta_\ell|$ (right) from simulated MC@NLO $t\bar{t}$ events, used to derive the smearing matrices (S).

distribution is varied according to Poisson statistics. The distributions are then unfolded, and the average value of the measured asymmetry is compared to the input value. We observe a linear relationship, thus validating the unfolding procedure. The constant of proportionality between the true and measured asymmetries deviates slightly from unity, leading to changes of up to 1% in the measured asymmetry. The effect of this bias is included in the systematic uncertainty from the unfolding. We also fit the distribution of the pulls ($[\text{measured}-\text{expected}]/\text{uncertainty}$) in the set of pseudoexperiments to a Gaussian function and verify that its standard deviation is consistent with unity.

7 Systematic uncertainties

Various systematic uncertainties have been evaluated, concerning mainly the detector performance and the modelling of the signal and background processes. Each systematic uncertainty is estimated using the difference between the results from the systematic variation and the central value.

The uncertainty from the jet-energy-scale (JES) corrections affects the AMWT $t\bar{t}$ solutions, as well as the event selection. It is estimated by varying the JES of jets within their uncertainties [14], and propagating this to the E_T^{miss} . The uncertainty in the lepton energy scale, which affects mainly the lepton p_T distributions, is estimated by varying the energy scale of electrons by $\pm 0.5\%$ (the uncertainty in muon energies is negligible in comparison), as estimated from comparisons between measured and simulated Z-boson events [40].

The uncertainty in the background subtraction is obtained by varying the normalisation of each background component, by $\pm 50\%$ for single-top-quark and diboson production, and by $\pm 100\%$ for Drell-Yan production and misidentified leptons, based on the estimates discussed in section 4.

The $t\bar{t}$ modelling and simulation uncertainties are evaluated by rederiving the A and S matrices using simulated events with the following variations: the jet energy resolution is increased by 5-10%, depending on the η of the jet [14]; the simulated pileup multiplicity distribution is changed within its uncertainty; the scale factors between data and simulation for the b-tagging efficiency [15], trigger efficiency, and lepton selection efficiency are shifted up and down by their uncertainties; the factorisation and renormalisation scales are together varied up and down by a factor of 2; the top-quark mass is varied by ± 1 GeV, based on the uncertainty in the combined Tevatron m_t measurement [41]; and the parton distribution functions are varied using the PDF4LHC formula [42]. In the simulated $t\bar{t}$ events, the τ -leptons are unpolarised. This affects the angular distributions of the electrons and muons coming from τ -lepton decays. The corresponding systematic effect is estimated by reweighting the τ -lepton decay distributions to reproduce the SM expectations. Since the origin of the discrepancy of the top-quark p_T distributions between data and simulation [35] is not fully understood, a 100% systematic uncertainty is applied to the top-quark p_T reweighting procedure discussed in section 3.

Finally, the results of the unfolding linearity tests discussed in section 6 are used to estimate the systematic uncertainty in the unfolding procedure. The systematic uncertainties in the unfolded A_C and A_C^{lep} measurements are summarised in table 3. The individual terms are added in quadrature to estimate the total systematic uncertainties. The dominant uncertainties are from the unfolding procedure for A_C , and the factorisation and renormalisation scale uncertainties for A_C^{lep} .

8 Results

The background-subtracted, unfolded, and normalised $\Delta|y_t|$ and $\Delta|\eta_\ell|$ distributions for the selected data events are shown in figure 4, along with the parton-level predictions obtained with the MC@NLO generator. The measured and predicted values are consistent.

Variable	A_C	A_C^{lep}
Experimental uncertainties		
Jet energy scale	0.003	0.001
Lepton energy scale	<0.001	<0.001
Background	0.001	0.001
Jet energy resolution	<0.001	<0.001
Pileup	<0.001	0.001
Scale factor for b tagging	<0.001	<0.001
Lepton selection	<0.001	<0.001
$t\bar{t}$ modelling uncertainties		
Fact. and renorm. scales	0.004	0.005
Top-quark mass	0.001	0.001
Parton distribution functions	<0.001	<0.001
τ -lepton decay	<0.001	<0.001
Top-quark p_T reweighting	0.001	<0.001
Unfolding	0.006	0.001
Total systematic uncertainty	0.008	0.006

Table 3. Systematic uncertainties in the unfolded values of A_C and A_C^{lep} from the sources listed.

The measured values of A_C and A_C^{lep} , unfolded to the parton level, are presented in table 4, where they are compared to the predictions from the MC@NLO $t\bar{t}$ sample and from NLO calculations [4]. Correlations between the contents of different bins, introduced by the unfolding process, are accounted for in the calculation of the uncertainties. The measured values are consistent with the expectations of the SM.

We also measure the dependence of the unfolded A_C^{lep} values on $M_{t\bar{t}}$, $|y_{t\bar{t}}|$, and $p_T^{t\bar{t}}$. To do so, we apply the same unfolding procedure on a two-dimensional distribution consisting of two bins in $\Delta|\eta_\ell|$ ($\Delta|\eta_\ell| > 0$ and $\Delta|\eta_\ell| < 0$) and three bins in $M_{t\bar{t}}$, $|y_{t\bar{t}}|$, or $p_T^{t\bar{t}}$. Since the regularisation procedure makes use of the second-derivative matrix, which is not well-defined for a two-bin distribution, the regularisation constraint is applied only along the $M_{t\bar{t}}$, $|y_{t\bar{t}}|$, and $p_T^{t\bar{t}}$ coordinates (this method was used previously in ref. [2]). The dependencies of the unfolded A_C^{lep} measurements on $M_{t\bar{t}}$, $|y_{t\bar{t}}|$, and $p_T^{t\bar{t}}$ are shown in figure 5. The corresponding values of A_C^{lep} are given in table 5. The results are consistent with the MC@NLO predictions. We did not measure the differential A_C values by this method, because the large migration of events between positive and negative $\Delta|y_t|$ was found to result in a biased response when only two bins in $\Delta|y_t|$ were used for the unfolding.

9 Summary

The first measurements in the dilepton final state of the difference in the $|y|$ distributions of top quarks and antiquarks and in the $|\eta|$ distributions of positive and negative leptons have been presented, in terms of the asymmetry variables A_C and A_C^{lep} , respectively. The data

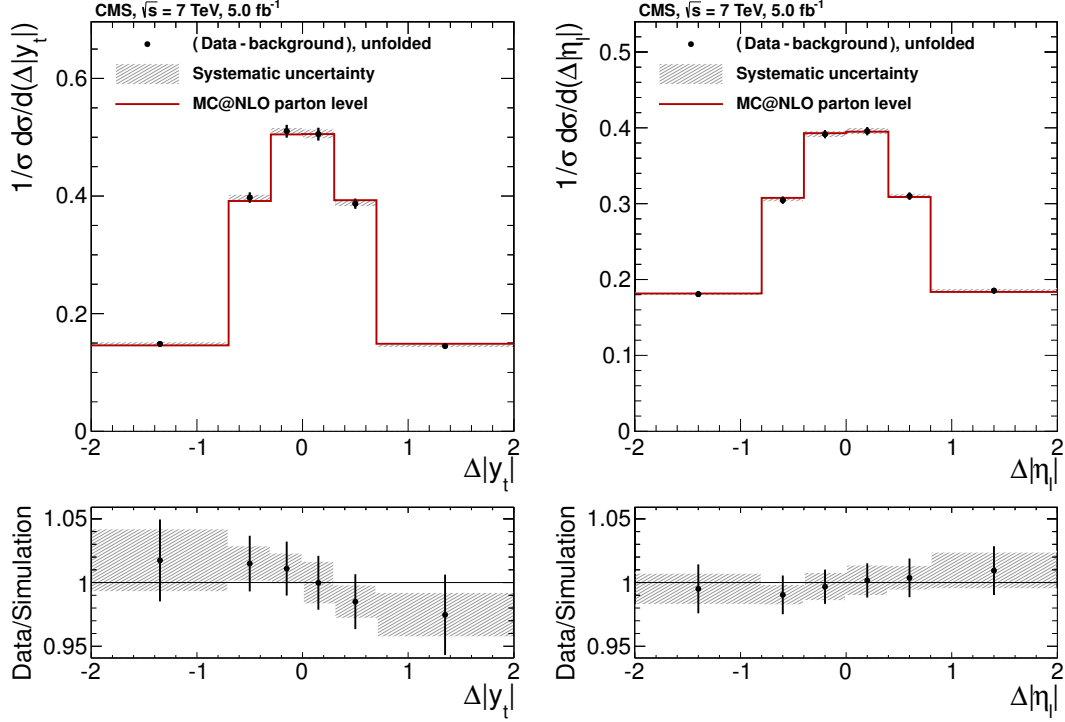


Figure 4. Top: background-subtracted and unfolded differential measurements of $\Delta|y_t|$ (left) and $\Delta|\eta_l|$ (right), both normalised to unit area (points), and the parton-level predictions from MC@NLO (histograms). Bottom: the ratio between the data and the MC@NLO prediction for $\Delta|y_t|$ (left) and $\Delta|\eta_l|$ (right). The error bars represent the statistical uncertainties in the data, while the systematic uncertainties are represented by the hatched band. The first and last bins include underflow and overflow events, respectively.

Variable	Data (unfolded)	MC@NLO prediction	NLO theory
A_C	$-0.010 \pm 0.017 \pm 0.008$	0.004 ± 0.001	0.0123 ± 0.0005
A_C^{lep}	$0.009 \pm 0.010 \pm 0.006$	0.004 ± 0.001	0.0070 ± 0.0003

Table 4. The unfolded A_C and A_C^{lep} measurements and parton-level predictions from the MC@NLO simulation and from NLO calculations [4]. For the data, the first uncertainty is statistical and the second is systematic. For the simulated results, the uncertainties are statistical only, while the uncertainties in the NLO calculations come from varying the factorisation and renormalisation scales up and down by a factor of two.

sample of $t\bar{t}$ events corresponds to a total integrated luminosity of 5.0 fb^{-1} from pp collisions at $\sqrt{s} = 7 \text{ TeV}$, collected by the CMS experiment at the LHC. The measured value of A_C is $-0.010 \pm 0.017 \text{ (stat.)} \pm 0.008 \text{ (syst.)}$ and of A_C^{lep} is $0.009 \pm 0.010 \text{ (stat.)} \pm 0.006 \text{ (syst.)}$, both unfolded to the parton level. The differential distributions of A_C^{lep} as a function of the $t\bar{t}$ system variables $M_{t\bar{t}}$, $|y_{t\bar{t}}|$, and $p_T^{t\bar{t}}$ have also been determined. All measurements are found to be in agreement with standard model expectations, and can help constrain theories beyond the standard model [3].

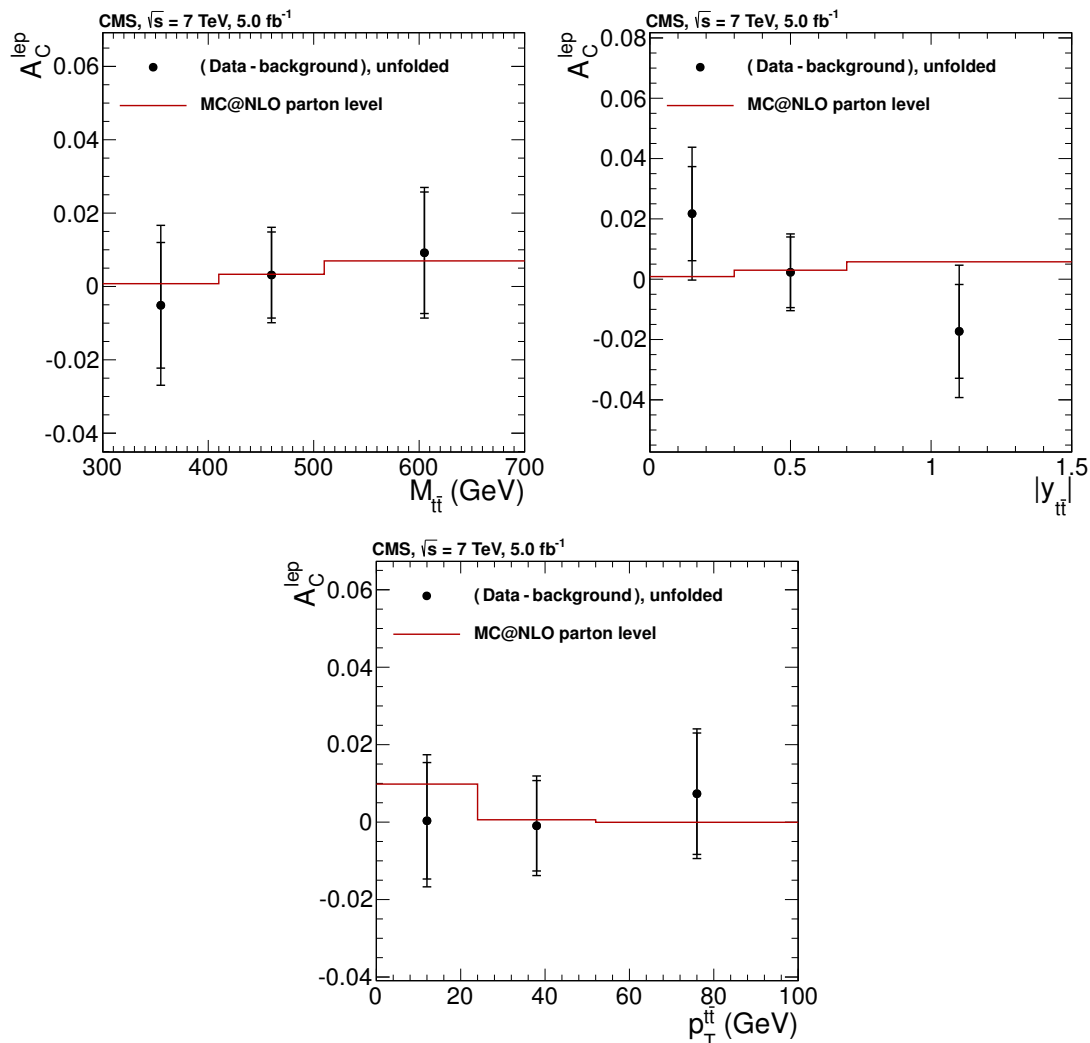


Figure 5. Dependence of the unfolded A_C^{lep} values (points) on $M_{t\bar{t}}$ (top left), $|y_{t\bar{t}}|$ (top right), and $p_T^{t\bar{t}}$ (bottom), and the parton-level predictions from MC@NLO (histograms). The inner and outer error bars represent the statistical and total uncertainties, respectively. The last bin of each plot includes overflow events.

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Bin	Data (unfolded)	MC@NLO prediction
$M_{t\bar{t}} < 410 \text{ GeV}$	$-0.005 \pm 0.017 \pm 0.013$	0.001 ± 0.008
$410 \leq M_{t\bar{t}} < 510 \text{ GeV}$	$0.003 \pm 0.012 \pm 0.006$	0.003 ± 0.007
$M_{t\bar{t}} \geq 510 \text{ GeV}$	$0.009 \pm 0.017 \pm 0.007$	0.007 ± 0.008
$ y_{t\bar{t}} < 0.3$	$0.022 \pm 0.016 \pm 0.016$	0.001 ± 0.009
$0.3 \leq y_{t\bar{t}} < 0.7$	$0.002 \pm 0.012 \pm 0.005$	0.003 ± 0.008
$ y_{t\bar{t}} \geq 0.7$	$-0.017 \pm 0.016 \pm 0.015$	0.006 ± 0.006
$p_T^{t\bar{t}} < 24 \text{ GeV}$	$0.000 \pm 0.015 \pm 0.008$	0.009 ± 0.007
$24 \leq p_T^{t\bar{t}} < 52 \text{ GeV}$	$-0.001 \pm 0.012 \pm 0.005$	0.000 ± 0.008
$p_T^{t\bar{t}} \geq 52 \text{ GeV}$	$0.007 \pm 0.016 \pm 0.006$	0.000 ± 0.007

Table 5. Measurements of the unfolded A_C^{lep} values in bins of $M_{t\bar{t}}$, $|y_{t\bar{t}}|$, and $p_T^{t\bar{t}}$, and the parton-level predictions from MC@NLO. For the data, the first uncertainty is statistical and the second is systematic. For the predictions, the uncertainties are statistical only.

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The CMS collaboration

Yerevan Physics Institute, Yerevan, Armenia

S. Chatrchyan, V. Khachatryan, A.M. Sirunyan, A. Tumasyan

Institut für Hochenergiephysik der OeAW, Wien, Austria

W. Adam, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan¹, M. Friedl, R. Frühwirth¹, V.M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler¹, W. Kiesenhofer, V. Knünz, M. Krammer¹, I. Krätschmer, D. Liko, I. Mikulec, D. Rabady², B. Rahbaran, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, W. Treberer-Treberspurg, W. Waltenberger, C.-E. Wulz¹

National Centre for Particle and High Energy Physics, Minsk, Belarus

V. Mossolov, N. Shumeiko, J. Suarez Gonzalez

Universiteit Antwerpen, Antwerpen, Belgium

S. Alderweireldt, M. Bansal, S. Bansal, T. Cornelis, E.A. De Wolf, X. Janssen, A. Knutsson, S. Luyckx, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

Vrije Universiteit Brussel, Brussel, Belgium

F. Blekman, S. Blyweert, J. D'Hondt, N. Heracleous, A. Kalogeropoulos, J. Keaveney, T.J. Kim, S. Lowette, M. Maes, A. Olbrechts, D. Strom, S. Tavernier, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Villella

Université Libre de Bruxelles, Bruxelles, Belgium

C. Caillol, B. Clerbaux, G. De Lentdecker, L. Favart, A.P.R. Gay, A. Léonard, P.E. Marage, A. Mohammadi, L. Perniè, T. Reis, T. Seva, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wang

Ghent University, Ghent, Belgium

V. Adler, K. Beernaert, L. Benucci, A. Cimmino, S. Costantini, S. Crucy, S. Dildick, G. Garcia, B. Klein, J. Lellouch, J. McCartin, A.A. Ocampo Rios, D. Ryckbosch, S. Salva Diblen, M. Sigamani, N. Strobbe, F. Thyssen, M. Tytgat, S. Walsh, E. Yazgan, N. Zaganidis

Université Catholique de Louvain, Louvain-la-Neuve, Belgium

S. Basegmez, C. Beluffi³, G. Bruno, R. Castello, A. Caudron, L. Ceard, G.G. Da Silva, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco⁴, J. Hollar, P. Jez, M. Komm, V. Lemaitre, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrkowski, A. Popov⁵, L. Quertenmont, M. Selvaggi, M. Vidal Marono, J.M. Vizan Garcia

Université de Mons, Mons, Belgium

N. Belyi, T. Caebergs, E. Daubie, G.H. Hammad

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

G.A. Alves, M. Correa Martins Junior, T. Martins, M.E. Pol, M.H.G. Souza

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil

W.L. Aldá Júnior, W. Carvalho, J. Chinellato⁶, A. Custódio, E.M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, H. Malbouisson, M. Malek, D. Matos Figueiredo, L. Mundim, H. Nogima, W.L. Prado Da Silva, J. Santaolalla, A. Santoro, A. Sznajder, E.J. Tonelli Manganote⁶, A. Vilela Pereira

Universidade Estadual Paulista ^a, Universidade Federal do ABC ^b, São Paulo, Brazil

C.A. Bernardes^b, F.A. Dias^{a,7}, T.R. Fernandez Perez Tomei^a, E.M. Gregores^b, P.G. Mercadante^b, S.F. Novaes^a, Sandra S. Padula^a

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

V. Genchev², P. Iaydjiev², A. Marinov, S. Piperov, M. Rodozov, G. Sultanov, M. Vutova

University of Sofia, Sofia, Bulgaria

A. Dimitrov, I. Glushkov, R. Hadjiiska, V. Kozhuharov, L. Litov, B. Pavlov, P. Petkov

Institute of High Energy Physics, Beijing, China

J.G. Bian, G.M. Chen, H.S. Chen, M. Chen, R. Du, C.H. Jiang, D. Liang, S. Liang, X. Meng, R. Plestina⁸, J. Tao, X. Wang, Z. Wang

State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China

C. Asawatangtrakuldee, Y. Ban, Y. Guo, Q. Li, W. Li, S. Liu, Y. Mao, S.J. Qian, D. Wang, L. Zhang, W. Zou

Universidad de Los Andes, Bogota, Colombia

C. Avila, C.A. Carrillo Montoya, L.F. Chaparro Sierra, C. Florez, J.P. Gomez, B. Gomez Moreno, J.C. Sanabria

Technical University of Split, Split, Croatia

N. Godinovic, D. Lelas, D. Polic, I. Puljak

University of Split, Split, Croatia

Z. Antunovic, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia

V. Brigljevic, K. Kadija, J. Luetic, D. Mekterovic, S. Morovic, L. Tikvica

University of Cyprus, Nicosia, Cyprus

A. Attikis, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis

Charles University, Prague, Czech Republic

M. Finger, M. Finger Jr.

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt

A.A. Abdelalim⁹, Y. Assran¹⁰, S. Elgammal¹¹, A. Ellithi Kamel¹², M.A. Mahmoud¹³, A. Radi^{11,14}

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

M. Kadastik, M. Müntel, M. Murumaa, M. Raidal, L. Rebane, A. Tiko

Department of Physics, University of Helsinki, Helsinki, Finland

P. Eerola, G. Fedi, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland

J. Härkönen, V. Karimäki, R. Kinnunen, M.J. Kortelainen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, T. Mäenpää, T. Peltola, E. Tuominen, J. Tuominiemi, E. Tuovinen, L. Wendland

Lappeenranta University of Technology, Lappeenranta, Finland

T. Tuuva

DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France

M. Besancon, F. Couderc, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, J. Malcles, A. Nayak, J. Rander, A. Rosowsky, M. Titov

Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France

S. Baffioni, F. Beaudette, P. Busson, C. Charlot, N. Daci, T. Dahms, M. Dalchenko, L. Dobrzynski, A. Florent, R. Granier de Cassagnac, P. Miné, C. Mironov, I.N. Naranjo, M. Nguyen, C. Ochando, P. Paganini, D. Sabes, R. Salerno, J.b. Sauvan, Y. Sirois, C. Veelken, Y. Yilmaz, A. Zabi

Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France

J.-L. Agram¹⁵, J. Andrea, D. Bloch, J.-M. Brom, E.C. Chabert, C. Collard, E. Conte¹⁵, F. Drouhin¹⁵, J.-C. Fontaine¹⁵, D. Gelé, U. Goerlach, C. Goetzmann, P. Juillot, A.-C. Le Bihan, P. Van Hove

Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France

S. Gadrat

Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France

S. Beauceron, N. Beaupere, G. Boudoul, S. Brochet, J. Chasserat, R. Chierici, D. Contardo², P. Depasse, H. El Mamouni, J. Fan, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, S. Perries, J.D. Ruiz Alvarez, L. Sgandurra, V. Sordini, M. Vander Donckt, P. Verdier, S. Viret, H. Xiao

Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia

Z. Tsamalaidze¹⁶

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany

C. Autermann, S. Beranek, M. Bontenackels, B. Calpas, M. Edelhoff, L. Feld, O. Hindrichs, K. Klein, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, B. Wittmer, V. Zhukov⁵

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany

M. Ata, J. Caudron, E. Dietz-Laursonn, D. Duchardt, M. Erdmann, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, D. Klingebiel, S. Knutzen, P. Kreuzer, M. Merschmeyer, A. Meyer, M. Olschewski, K. Padeken, P. Papacz, H. Reithler, S.A. Schmitz, L. Sonnenschein, D. Teyssier, S. Thüer, M. Weber

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany

V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, J. Lingemann², A. Nowack, I.M. Nugent, L. Perchalla, O. Pooth, A. Stahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany

I. Asin, N. Bartosik, J. Behr, W. Behrenhoff, U. Behrens, A.J. Bell, M. Bergholz¹⁷, A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, S. Choudhury, F. Costanza, C. Diez Pardos, S. Dooling, T. Dorland, G. Eckerlin, D. Eckstein, T. Eichhorn, G. Flucke, A. Geiser, A. Grebenyuk, P. Gunnellini, S. Habib, J. Hauk, G. Hellwig, M. Hempel, D. Horton, H. Jung, M. Kasemann, P. Katsas, J. Kieseler, C. Kleinwort, M. Krämer, D. Krücker, W. Lange, J. Leonard, K. Lipka, W. Lohmann¹⁷, B. Lutz, R. Mankel, I. Marfin, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, O. Novgorodova, F. Nowak, E. Ntomari, H. Perrey, A. Petrukhin, D. Pitzl, R. Placakyte, A. Raspereza, P.M. Ribeiro Cipriano, C. Riedl, E. Ron, M.Ö. Sahin, J. Salfeld-Nebgen, P. Saxena, R. Schmidt¹⁷, T. Schoerner-Sadenius, M. Schröder, M. Stein, A.D.R. Vargas Trevino, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany

M. Aldaya Martin, V. Blobel, H. Enderle, J. Erfle, E. Garutti, K. Goebel, M. Görner, M. Gosselink, J. Haller, R.S. Höing, H. Kirschenmann, R. Klanner, R. Kogler, J. Lange, T. Lapsien, T. Lenz, I. Marchesini, J. Ott, T. Peiffer, N. Pietsch, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, M. Seidel, J. Sibille¹⁸, V. Sola, H. Stadie, G. Steinbrück, D. Troendle, E. Usai, L. Vanelderen

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

C. Barth, C. Baus, J. Berger, C. Böser, E. Butz, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, M. Guthoff², F. Hartmann², T. Hauth², H. Held, K.H. Hoffmann, U. Husemann, I. Katkov⁵, A. Kornmayer², E. Kuznetsova, P. Lobelle Pardo, D. Martschei, M.U. Mozer, Th. Müller, M. Niegel, A. Nürnberg, O. Oberst, G. Quast, K. Rabbertz, F. Ratnikov, S. Röcker, F.-P. Schilling, G. Schott, H.J. Simonis, F.M. Stober, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, R. Wolf, M. Zeise

Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece

G. Anagnostou, G. Daskalakis, T. Gerasis, S. Kesisoglou, A. Kyriakis, D. Loukas, A. Markou, C. Markou, A. Psallidas, I. Topsis-giotis

University of Athens, Athens, Greece

L. Gouskos, A. Panagiotou, N. Saoulidou, E. Stiliaris

University of Ioánnina, Ioánnina, Greece

X. Aslanoglou, I. Evangelou², G. Flouris, C. Foudas², J. Jones, P. Kokkas, N. Manthos, I. Papadopoulos, E. Paradas

Wigner Research Centre for Physics, Budapest, Hungary

G. Bencze², C. Hajdu, P. Hidas, D. Horvath¹⁹, F. Sikler, V. Veszpremi, G. Vesztergombi²⁰, A.J. Zsigmond

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

N. Beni, S. Czellar, J. Molnar, J. Palinkas, Z. Szillasi

University of Debrecen, Debrecen, Hungary

J. Karancsi, P. Raics, Z.L. Trocsanyi, B. Ujvari

National Institute of Science Education and Research, Bhubaneswar, India

S.K. Swain

Panjab University, Chandigarh, India

S.B. Beri, V. Bhatnagar, N. Dhingra, R. Gupta, M. Kaur, M.Z. Mehta, M. Mittal, N. Nishu, A. Sharma, J.B. Singh

University of Delhi, Delhi, India

Ashok Kumar, Arun Kumar, S. Ahuja, A. Bhardwaj, B.C. Choudhary, A. Kumar, S. Malhotra, M. Naimuddin, K. Ranjan, V. Sharma, R.K. Shivpuri

Saha Institute of Nuclear Physics, Kolkata, India

S. Banerjee, S. Bhattacharya, K. Chatterjee, S. Dutta, B. Gomber, Sa. Jain, Sh. Jain, R. Khurana, A. Modak, S. Mukherjee, D. Roy, S. Sarkar, M. Sharan, A.P. Singh

Bhabha Atomic Research Centre, Mumbai, India

A. Abdulsalam, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty², L.M. Pant, P. Shukla, A. Topkar

Tata Institute of Fundamental Research - EHEP, Mumbai, India

T. Aziz, R.M. Chatterjee, S. Ganguly, S. Ghosh, M. Guchait²¹, A. Gurtu²², G. Kole, S. Kumar, M. Maity²³, G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage²⁴

Tata Institute of Fundamental Research - HECR, Mumbai, India

S. Banerjee, S. Dugad

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran

H. Arfaei, H. Bakhshiansohi, H. Behnamian, S.M. Etesami²⁵, A. Fahim²⁶, A. Jafari, M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi, B. Safarzadeh²⁷, M. Zeinali

University College Dublin, Dublin, Ireland

M. Grunewald

INFN Sezione di Bari ^a, Università di Bari ^b, Politecnico di Bari ^c, Bari, Italy

M. Abbrescia^{a,b}, L. Barbone^{a,b}, C. Calabria^{a,b}, S.S. Chhibra^{a,b}, A. Colaleo^a, D. Creanza^{a,c}, N. De Filippis^{a,c}, M. De Palma^{a,b}, L. Fiore^a, G. Iaselli^{a,c}, G. Maggi^{a,c}, M. Maggi^a, B. Marangelli^{a,b}, S. My^{a,c}, S. Nuzzo^{a,b}, N. Pacifico^a, A. Pompili^{a,b}, G. Pugliese^{a,c}, R. Radogna^{a,b}, G. Selvaggi^{a,b}, L. Silvestris^a, G. Singh^{a,b}, R. Venditti^{a,b}, P. Verwilligen^a, G. Zito^a

INFN Sezione di Bologna ^a, Università di Bologna ^b, Bologna, Italy

G. Abbiendi^a, A.C. Benvenuti^a, D. Bonacorsi^{a,b}, S. Braibant-Giacomelli^{a,b}, L. Brigliadori^{a,b}, R. Campanini^{a,b}, P. Capiluppi^{a,b}, A. Castro^{a,b}, F.R. Cavallo^a, G. Codispoti^{a,b}, M. Cuffiani^{a,b}, G.M. Dallavalle^a, F. Fabbri^a, A. Fanfani^{a,b}, D. Fasanella^{a,b}, P. Giacomelli^a, C. Grandi^a, L. Guiducci^{a,b}, S. Marcellini^a, G. Masetti^a, M. Meneghelli^{a,b}, A. Montanari^a, F.L. Navarria^{a,b}, F. Odorici^a, A. Perrotta^a, F. Primavera^{a,b}, A.M. Rossi^{a,b}, T. Rovelli^{a,b}, G.P. Siroli^{a,b}, N. Tosi^{a,b}, R. Travaglini^{a,b}

INFN Sezione di Catania ^a, Università di Catania ^b, CSFNSM ^c, Catania, Italy

S. Albergo^{a,b}, G. Cappello^a, M. Chiorboli^{a,b}, S. Costa^{a,b}, F. Giordano^{a,c,2}, R. Potenza^{a,b}, A. Tricomi^{a,b}, C. Tuve^{a,b}

INFN Sezione di Firenze ^a, Università di Firenze ^b, Firenze, Italy

G. Barbagli^a, V. Ciulli^{a,b}, C. Civinini^a, R. D'Alessandro^{a,b}, E. Focardi^{a,b}, E. Gallo^a, S. Gonzi^{a,b}, V. Gori^{a,b}, P. Lenzi^{a,b}, M. Meschini^a, S. Paoletti^a, G. Sguazzoni^a, A. Tropiano^{a,b}

INFN Laboratori Nazionali di Frascati, Frascati, Italy

L. Benussi, S. Bianco, F. Fabbri, D. Piccolo

INFN Sezione di Genova ^a, Università di Genova ^b, Genova, Italy

P. Fabbricatore^a, R. Ferretti^{a,b}, F. Ferro^a, M. Lo Vetere^{a,b}, R. Musenich^a, E. Robutti^a, S. Tosi^{a,b}

INFN Sezione di Milano-Bicocca ^a, Università di Milano-Bicocca ^b, Milano, Italy

M.E. Dinardo^{a,b}, S. Fiorendi^{a,b,2}, S. Gennai^a, R. Gerosa, A. Ghezzi^{a,b}, P. Govoni^{a,b}, M.T. Lucchini^{a,b,2}, S. Malvezzi^a, R.A. Manzoni^{a,b,2}, A. Martelli^{a,b,2}, B. Marzocchi, D. Menasce^a, L. Moroni^a, M. Paganoni^{a,b}, D. Pedrini^a, S. Ragazzi^{a,b}, N. Redaelli^a, T. Tabarelli de Fatis^{a,b}

INFN Sezione di Napoli ^a, Università di Napoli 'Federico II' ^b, Università della Basilicata (Potenza) ^c, Università G. Marconi (Roma) ^d, Napoli, Italy

S. Buontempo^a, N. Cavallo^{a,c}, S. Di Guida^{a,d}, F. Fabozzi^{a,c}, A.O.M. Iorio^{a,b}, L. Lista^a, S. Meola^{a,d,2}, M. Merola^a, P. Paolucci^{a,2}

INFN Sezione di Padova ^a, Università di Padova ^b, Università di Trento (Trento) ^c, Padova, Italy

P. Azzi^a, N. Bacchetta^a, M. Bellato^a, D. Bisello^{a,b}, A. Branca^{a,b}, R. Carlin^{a,b}, P. Checchia^a, T. Dorigo^a, U. Dosselli^a, M. Galanti^{a,b,2}, F. Gasparini^{a,b}, U. Gasparini^{a,b}, P. Giubilato^{a,b}, A. Gozzelino^a, K. Kanishchev^{a,c}, S. Lacaprara^a, I. Lazzizzera^{a,c}, M. Margoni^{a,b}, A.T. Meneguzzo^{a,b}, F. Montecassiano^a, M. Passaseo^a, J. Pazzini^{a,b}, N. Pozzobon^{a,b}, P. Ronchese^{a,b}, F. Simonetto^{a,b}, E. Torassa^a, M. Tosi^{a,b}, P. Zotto^{a,b}, A. Zucchetta^{a,b}

INFN Sezione di Pavia ^a, Università di Pavia ^b, Pavia, Italy

M. Gabusi^{a,b}, S.P. Ratti^{a,b}, C. Riccardi^{a,b}, P. Salvini^a, P. Vitulo^{a,b}

INFN Sezione di Perugia ^a, Università di Perugia ^b, Perugia, Italy

M. Biasini^{a,b}, G.M. Bilei^a, L. Fanò^{a,b}, P. Lariccia^{a,b}, G. Mantovani^{a,b}, M. Menichelli^a, F. Romeo^{a,b}, A. Saha^a, A. Santocchia^{a,b}, A. Spiezia^{a,b}

INFN Sezione di Pisa ^a, Università di Pisa ^b, Scuola Normale Superiore di Pisa ^c, Pisa, Italy

K. Androsov^{a,28}, P. Azzurri^a, G. Bagliesi^a, J. Bernardini^a, T. Boccali^a, G. Broccolo^{a,c}, R. Castaldi^a, M.A. Ciocci^{a,28}, R. Dell'Orso^a, F. Fiori^{a,c}, L. Foà^{a,c}, A. Giassi^a, M.T. Grippo^{a,28}, A. Kraan^a, F. Ligabue^{a,c}, T. Lomtadze^a, L. Martini^{a,b}, A. Messineo^{a,b}, C.S. Moon^{a,29}, F. Palla^{a,2}, A. Rizzi^{a,b}, A. Savoy-Navarro^{a,30}, A.T. Serban^a, P. Spagnolo^a, P. Squillacioti^{a,28}, R. Tenchini^a, G. Tonelli^{a,b}, A. Venturi^a, P.G. Verдини^a, C. Vernieri^{a,c}

INFN Sezione di Roma ^a, Università di Roma ^b, Roma, Italy

L. Barone^{a,b}, F. Cavallari^a, D. Del Re^{a,b}, M. Diemoz^a, M. Grassi^{a,b}, C. Jorda^a, E. Longo^{a,b}, F. Margaroli^{a,b}, P. Meridiani^a, F. Micheli^{a,b}, S. Nourbakhsh^{a,b}, G. Organtini^{a,b}, R. Paramatti^a, S. Rahatlou^{a,b}, C. Rovelli^a, L. Soffi^{a,b}, P. Traczyk^{a,b}

INFN Sezione di Torino ^a, Università di Torino ^b, Università del Piemonte Orientale (Novara) ^c, Torino, Italy

N. Amapane^{a,b}, R. Arcidiacono^{a,c}, S. Argiro^{a,b}, M. Arneodo^{a,c}, R. Bellan^{a,b}, C. Biino^a, N. Cartiglia^a, S. Casasso^{a,b}, M. Costa^{a,b}, A. Degano^{a,b}, N. Demaria^a, C. Mariotti^a, S. Maselli^a, E. Migliore^{a,b}, V. Monaco^{a,b}, M. Musich^a, M.M. Obertino^{a,c}, G. Ortona^{a,b}, L. Pacher^{a,b}, N. Pastrone^a, M. Pelliccioni^{a,2}, A. Potenza^{a,b}, A. Romero^{a,b}, M. Ruspa^{a,c}, R. Sacchi^{a,b}, A. Solano^{a,b}, A. Staiano^a, U. Tamponi^a

INFN Sezione di Trieste ^a, Università di Trieste ^b, Trieste, Italy

S. Belforte^a, V. Candelise^{a,b}, M. Casarsa^a, F. Cossutti^a, G. Della Ricca^{a,b}, B. Gobbo^a, C. La Licata^{a,b}, M. Marone^{a,b}, D. Montanino^{a,b}, A. Penzo^a, A. Schizzi^{a,b}, T. Umer^{a,b}, A. Zanetti^a

Kangwon National University, Chunchon, Korea

S. Chang, T.Y. Kim, S.K. Nam

Kyungpook National University, Daegu, Korea

D.H. Kim, G.N. Kim, J.E. Kim, M.S. Kim, D.J. Kong, S. Lee, Y.D. Oh, H. Park, D.C. Son

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea

J.Y. Kim, Zero J. Kim, S. Song

Korea University, Seoul, Korea

S. Choi, D. Gyun, B. Hong, M. Jo, H. Kim, Y. Kim, K.S. Lee, S.K. Park, Y. Roh

University of Seoul, Seoul, Korea

M. Choi, J.H. Kim, C. Park, I.C. Park, S. Park, G. Ryu

Sungkyunkwan University, Suwon, Korea

Y. Choi, Y.K. Choi, J. Goh, E. Kwon, B. Lee, J. Lee, H. Seo, I. Yu

Vilnius University, Vilnius, Lithuania

A. Juodagalvis

National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia

J.R. Komaragiri

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico

H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz³¹, R. Lopez-Fernandez, J. Martínez-Ortega, A. Sanchez-Hernandez, L.M. Villasenor-Cendejas

Universidad Iberoamericana, Mexico City, Mexico

S. Carrillo Moreno, F. Vazquez Valencia

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

H.A. Salazar Ibarguen

Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico

E. Casimiro Linares, A. Morelos Pineda

University of Auckland, Auckland, New Zealand

D. Krofcheck

University of Canterbury, Christchurch, New Zealand

P.H. Butler, R. Doesburg, S. Reucroft

National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan

A. Ahmad, M. Ahmad, M.I. Asghar, J. Butt, Q. Hassan, H.R. Hoorani, W.A. Khan, T. Khurshid, S. Qazi, M.A. Shah, M. Shoaib

National Centre for Nuclear Research, Swierk, Poland

H. Bialkowska, M. Bluj³², B. Boimska, T. Frueboes, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, G. Wrochna, P. Zalewski

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland

G. Brona, K. Bunkowski, M. Cwiok, W. Dominik, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, W. Wolszczak

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal

P. Bargassa, C. Beirão Da Cruz E Silva, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, F. Nguyen, J. Rodrigues Antunes, J. Seixas, J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia

S. Afanasiev, I. Golutvin, V. Karjavin, V. Konoplyanikov, V. Korenkov, G. Kozlov, A. Lanev, A. Malakhov, V. Matveev³³, P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov, S. Shulha, N. Skatchkov, V. Smirnov, E. Tikhonenko, A. Zarubin

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia

V. Golovtsov, Y. Ivanov, V. Kim³⁴, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev, An. Vorobyev

Institute for Nuclear Research, Moscow, Russia

Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, M. Kirsanov, N. Krasnikov, A. Pashenkov, D. Tlisov, A. Toropin

Institute for Theoretical and Experimental Physics, Moscow, Russia

V. Epshteyn, V. Gavrilov, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, A. Spiridonov, V. Stolin, E. Vlasov, A. Zhokin

P.N. Lebedev Physical Institute, Moscow, Russia

V. Andreev, M. Azarkin, I. Dremin, M. Kirakosyan, A. Leonidov, G. Mesyats, S.V. Rusakov, A. Vinogradov

Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia

A. Belyaev, E. Boos, V. Bunichev, M. Dubinin⁷, L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, I. Lokhtin, S. Obraztsov, M. Perfilov, V. Savrin, N. Tsirova

State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Kachanov, A. Kalinin, D. Konstantinov, V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia

P. Adzic³⁵, M. Djordjevic, M. Ekmedzic, J. Milosevic

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain

M. Aguilar-Benitez, J. Alcaraz Maestre, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo Llatas², N. Colino, B. De La Cruz, A. Delgado Peris, D. Domínguez Vázquez, C. Fernandez Bedoya, J.P. Fernández Ramos, A. Ferrando, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, G. Merino, E. Navarro De Martino, A. Pérez-Calero Yzquierdo, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, M.S. Soares, C. Willmott

Universidad Autónoma de Madrid, Madrid, Spain

C. Albajar, J.F. de Trocóniz, M. Missiroli

Universidad de Oviedo, Oviedo, Spain

H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain

J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, J. Duarte Campderros, M. Fernandez, G. Gomez, J. Gonzalez Sanchez, A. Graziano, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, J. Piedra Gomez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, A. Benaglia, J. Bendavid, L. Benhabib, J.F. Benitez, C. Bernet⁸, G. Bianchi, P. Bloch, A. Bocci, A. Bonato, O. Bondu, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, S. Colafranceschi³⁶, M. D'Alfonso, D. d'Enterria, A. Dabrowski, A. David, F. De Guio, A. De Roeck, S. De Visscher, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, J. Eugster, G. Franzoni, W. Funk, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Girone, M. Giunta, F. Glege, R. Gomez-Reino Garrido, S. Gowdy, R. Guida, J. Hammer, M. Hansen, P. Harris, V. Innocente, P. Janot, E. Karavakis, K. Kousouris, K. Krajczar, P. Lecoq, C. Lourenço, N. Magini, L. Malgeri, M. Mannelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, F. Moortgat, M. Mulders, P. Musella, L. Orsini, E. Palencia Cortezon, E. Perez, L. Perrozzi, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, M. Plagge, A. Racz, W. Reece, G. Rolandi³⁷, M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas³⁸, D. Spiga, J. Steggemann, B. Stieger, M. Stoye, A. Tsirou, G.I. Veres²⁰, J.R. Vlimant, H.K. Wöhri, W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland

W. Bertl, K. Deiters, W. Erdmann, R. Horisberger, Q. Ingram, H.C. Kaestli, S. König, D. Kotlinski, U. Langenegger, D. Renker, T. Rohe

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

F. Bachmair, L. Bäni, L. Bianchini, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, A. Deisher, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, P. Eller, C. Grab, D. Hits, W. Lustermann, B. Mangano, A.C. Marini, P. Martinez Ruiz del Arbol, D. Meister, N. Mohr, C. Nägeli³⁹, P. Nef, F. Nessi-Tedaldi, F. Pandolfi, L. Pape, F. Pauss, M. Peruzzi, M. Quittnat, F.J. Ronga, M. Rossini, A. Starodumov⁴⁰, M. Takahashi, L. Tauscher[†], K. Theofilatos, D. Treille, R. Wallny, H.A. Weber

Universität Zürich, Zurich, Switzerland

C. Amsler⁴¹, M.F. Canelli, V. Chiochia, A. De Cosa, C. Favaro, A. Hinzmann, T. Hreus, M. Ivova Rikova, B. Kilminster, B. Millan Mejias, J. Ngadiuba, P. Robmann, H. Snoek, S. Taroni, M. Verzetti, Y. Yang

National Central University, Chung-Li, Taiwan

M. Cardaci, K.H. Chen, C. Ferro, C.M. Kuo, S.W. Li, W. Lin, Y.J. Lu, R. Volpe, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan

P. Bartalini, P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, P.H. Chen, C. Dietz, U. Grundler, W.-S. Hou, Y. Hsiung, K.Y. Kao, Y.J. Lei, Y.F. Liu, R.-S. Lu, D. Majumder, E. Petrakou, X. Shi, J.G. Shiu, Y.M. Tzeng, M. Wang, R. Wilken

Chulalongkorn University, Bangkok, Thailand

B. Asavapibhop, N. Suwonjandee

Cukurova University, Adana, Turkey

A. Adiguzel, M.N. Bakirci⁴², S. Cerci⁴³, C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, E. Garpinar, I. Hos, E.E. Kangal, A. Kayis Topaksu, G. Onengut⁴⁴, K. Ozdemir, S. Ozturk⁴², A. Polatoz, K. Sogut⁴⁵, D. Sunar Cerci⁴³, B. Tali⁴³, H. Topakli⁴², M. Vergili

Middle East Technical University, Physics Department, Ankara, Turkey

I.V. Akin, T. Aliev, B. Bilin, S. Bilmis, M. Deniz, H. Gamsizkan, A.M. Guler, G. Karapinar⁴⁶, K. Ocalan, A. Ozpineci, M. Serin, R. Sever, U.E. Surat, M. Yalvac, M. Zeyrek

Bogazici University, Istanbul, Turkey

E. Gülmez, B. Isildak⁴⁷, M. Kaya⁴⁸, O. Kaya⁴⁸, S. Ozkorucuklu⁴⁹

Istanbul Technical University, Istanbul, Turkey

H. Bahtiyar⁵⁰, E. Barlas, K. Cankocak, Y.O. Günaydin⁵¹, F.I. Vardarli, M. Yücel

National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine

L. Levchuk, P. Sorokin

University of Bristol, Bristol, United Kingdom

J.J. Brooke, E. Clement, D. Cussans, H. Flacher, R. Frazier, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, J. Jacob, L. Kreczko, C. Lucas, Z. Meng, D.M. Newbold⁵², S. Paramesvaran, A. Poll, S. Senkin, V.J. Smith, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom

K.W. Bell, A. Belyaev⁵³, C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Ilic, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, W.J. Womersley, S.D. Worm

Imperial College, London, United Kingdom

M. Baber, R. Bainbridge, O. Buchmuller, D. Burton, D. Colling, N. Cripps, M. Cutajar, P. Dauncey, G. Davies, M. Della Negra, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, M. Jarvis, G. Karapostoli, M. Kenzie, R. Lane, R. Lucas⁵², L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko⁴⁰, J. Pela, M. Pesaresi, K. Petridis, M. Pioppi⁵⁴, D.M. Raymond, S. Rogerson, A. Rose, C. Seez, P. Sharp[†], A. Sparrow, A. Tapper, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle

Brunel University, Uxbridge, United Kingdom

J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, D. Leggat, D. Leslie, W. Martin, I.D. Reid, P. Symonds, L. Teodorescu, M. Turner

Baylor University, Waco, USA

J. Dittmann, K. Hatakeyama, A. Kasmi, H. Liu, T. Scarborough

The University of Alabama, Tuscaloosa, USA

O. Charaf, S.I. Cooper, C. Henderson, P. Rumerio

Boston University, Boston, USA

A. Avetisyan, T. Bose, C. Fantasia, A. Heister, P. Lawson, D. Lazic, C. Richardson, J. Rohlf, D. Sperka, J. St. John, L. Sulak

Brown University, Providence, USA

J. Alimena, S. Bhattacharya, G. Christopher, D. Cutts, Z. Demiragli, A. Ferapontov, A. Garabedian, U. Heintz, S. Jabeen, G. Kukartsev, E. Laird, G. Landsberg, M. Luk, M. Narain, M. Segala, T. Sinthuprasith, T. Speer, J. Swanson

University of California, Davis, Davis, USA

R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, R. Erbacher, M. Gardner, W. Ko, A. Kopecky, R. Lander, T. Miceli, M. Mulhearn, D. Pellett, J. Pilot, F. Ricci-Tam, B. Rutherford, M. Searle, S. Shalhout, J. Smith, M. Squires, M. Tripathi, S. Wilbur, R. Yohay

University of California, Los Angeles, USA

V. Andreev, D. Cline, R. Cousins, S. Erhan, P. Everaerts, C. Farrell, M. Felcini, J. Hauser, M. Ignatenko, C. Jarvis, G. Rakness, P. Schlein[†], E. Takasugi, V. Valuev, M. Weber

University of California, Riverside, Riverside, USA

J. Babb, R. Clare, J. Ellison, J.W. Gary, G. Hanson, J. Heilman, P. Jandir, F. Lacroix, H. Liu, O.R. Long, A. Luthra, M. Malberti, H. Nguyen, A. Shrinivas, J. Sturdy, S. Sumowidagdo, S. Wimpenny

University of California, San Diego, La Jolla, USA

W. Andrews, J.G. Branson, G.B. Cerati, S. Cittolin, R.T. D’Agnolo, D. Evans, A. Holzner, R. Kelley, D. Klein, D. Kovalskyi, M. Lebourgeois, J. Letts, I. Macneill, S. Padhi, C. Palmer, M. Pieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech⁵⁵, F. Würthwein, A. Yagil, J. Yoo

University of California, Santa Barbara, Santa Barbara, USA

D. Barge, J. Bradmiller-Feld, C. Campagnari, T. Danielson, A. Dishaw, K. Flowers, M. Franco Sevilla, P. Geffert, C. George, F. Golf, J. Incandela, C. Justus, R. Magaña Villalba, N. Mccoll, V. Pavlunin, J. Richman, R. Rossin, D. Stuart, W. To, C. West

California Institute of Technology, Pasadena, USA

A. Apresyan, A. Bornheim, J. Bunn, Y. Chen, E. Di Marco, J. Duarte, D. Kcira, A. Mott, H.B. Newman, C. Pena, C. Rogan, M. Spiropulu, V. Timciuc, R. Wilkinson, S. Xie, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA

V. Azzolini, A. Calamba, R. Carroll, T. Ferguson, Y. Iiyama, D.W. Jang, M. Paulini, J. Russ, H. Vogel, I. Vorobiev

University of Colorado at Boulder, Boulder, USA

J.P. Cumalat, B.R. Drell, W.T. Ford, A. Gaz, E. Luiggi Lopez, U. Nauenberg, J.G. Smith, K. Stenson, K.A. Ulmer, S.R. Wagner

Cornell University, Ithaca, USA

J. Alexander, A. Chatterjee, N. Eggert, L.K. Gibbons, W. Hopkins, A. Khukhunaishvili, B. Kreis, N. Mirman, G. Nicolas Kaufman, J.R. Patterson, A. Ryd, E. Salvati, W. Sun, W.D. Teo, J. Thom, J. Thompson, J. Tucker, Y. Weng, L. Winstrom, P. Wittich

Fairfield University, Fairfield, USA

D. Winn

Fermi National Accelerator Laboratory, Batavia, USA

S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana, S. Cihangir, V.D. Elvira, I. Fisk, J. Freeman, Y. Gao, E. Gottschalk, L. Gray, D. Green, S. Grünendahl, O. Gutsche, D. Hare, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, K. Kaadze, B. Klima, S. Kwan, J. Linacre, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, V.I. Martinez Outschoorn, S. Maruyama, D. Mason, P. McBride, K. Mishra, S. Mrenna, Y. Musienko³³, S. Nahn, C. Newman-Holmes, V. O’Dell, O. Prokofyev, N. Ratnikova, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, A. Whitbeck, J. Whitmore, W. Wu, F. Yang, J.C. Yun

University of Florida, Gainesville, USA

D. Acosta, P. Avery, D. Bourilkov, T. Cheng, S. Das, M. De Gruttola, G.P. Di Giovanni, D. Dobur, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Hugon, B. Kim, J. Konigsberg,

A. Korytov, A. Kropivnitskaya, T. Kypreos, J.F. Low, K. Matchev, P. Milenovic⁵⁶, G. Mitselmakher, L. Muniz, A. Rinkevicius, L. Shchutska, N. Skhirtladze, M. Snowball, J. Yelton, M. Zakaria

Florida International University, Miami, USA

V. Gaultney, S. Hewamanage, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida State University, Tallahassee, USA

T. Adams, A. Askew, J. Bochenek, J. Chen, B. Diamond, J. Haas, S. Hagopian, V. Hagopian, K.F. Johnson, H. Prosper, V. Veeraraghavan, M. Weinberg

Florida Institute of Technology, Melbourne, USA

M.M. Baarmand, B. Dorney, M. Hohlmann, H. Kalakhety, F. Yumiceva

University of Illinois at Chicago (UIC), Chicago, USA

M.R. Adams, L. Apanasevich, V.E. Bazterra, R.R. Betts, I. Bucinskaite, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, P. Kurt, D.H. Moon, C. O'Brien, C. Silkworth, P. Turner, N. Varelas

The University of Iowa, Iowa City, USA

U. Akgun, E.A. Albayrak⁵⁰, B. Bilki⁵⁷, W. Clarida, K. Dilsiz, F. Duru, M. Haytmyradov, J.-P. Merlo, H. Mermerkaya⁵⁸, A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok⁵⁰, R. Rahmat, S. Sen, P. Tan, E. Tiras, J. Wetzel, T. Yetkin⁵⁹, K. Yi

Johns Hopkins University, Baltimore, USA

B.A. Barnett, B. Blumenfeld, S. Bolognesi, D. Fehling, A.V. Gritsan, P. Maksimovic, C. Martin, M. Swartz

The University of Kansas, Lawrence, USA

P. Baringer, A. Bean, G. Benelli, R.P. Kenny III, M. Murray, D. Noonan, S. Sanders, J. Sekaric, R. Stringer, Q. Wang, J.S. Wood

Kansas State University, Manhattan, USA

A.F. Barfuss, I. Chakaberia, A. Ivanov, S. Khalil, M. Makouski, Y. Maravin, L.K. Saini, S. Shrestha, I. Svintradze

Lawrence Livermore National Laboratory, Livermore, USA

J. Gronberg, D. Lange, F. Rebassoo, D. Wright

University of Maryland, College Park, USA

A. Baden, B. Calvert, S.C. Eno, J.A. Gomez, N.J. Hadley, R.G. Kellogg, T. Kolberg, Y. Lu, M. Marionneau, A.C. Mignerey, K. Pedro, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar

Massachusetts Institute of Technology, Cambridge, USA

A. Apyan, R. Barbieri, G. Bauer, W. Busza, I.A. Cali, M. Chan, L. Di Matteo, V. Dutta, G. Gomez Ceballos, M. Goncharov, D. Gulhan, M. Klute, Y.S. Lai, Y.-J. Lee, A. Levin, P.D. Luckey, T. Ma, C. Paus, D. Ralph, C. Roland, G. Roland, G.S.F. Stephans, F. Stöckli, K. Sumorok, D. Velicanu, J. Veverka, B. Wyslouch, M. Yang, A.S. Yoon, M. Zanetti, V. Zhukova

University of Minnesota, Minneapolis, USA

B. Dahmes, A. De Benedetti, A. Gude, S.C. Kao, K. Klapoetke, Y. Kubota, J. Mans, N. Pastika, R. Rusack, A. Singovsky, N. Tambe, J. Turkewitz

University of Mississippi, Oxford, USA

J.G. Acosta, L.M. Cremaldi, R. Kroeger, S. Oliveros, L. Perera, D.A. Sanders, D. Summers

University of Nebraska-Lincoln, Lincoln, USA

E. Avdeeva, K. Bloom, S. Bose, D.R. Claes, A. Dominguez, R. Gonzalez Suarez, J. Keller, D. Knowlton, I. Kravchenko, J. Lazo-Flores, S. Malik, F. Meier, G.R. Snow

State University of New York at Buffalo, Buffalo, USA

J. Dolen, A. Godshalk, I. Iashvili, S. Jain, A. Kharchilava, A. Kumar, S. Rappoccio

Northeastern University, Boston, USA

G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, J. Haley, A. Massironi, D. Nash, T. Orimoto, D. Trocino, D. Wood, J. Zhang

Northwestern University, Evanston, USA

A. Anastassov, K.A. Hahn, A. Kubik, L. Lusito, N. Mucia, N. Odell, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, K. Sung, M. Velasco, S. Won

University of Notre Dame, Notre Dame, USA

D. Berry, A. Brinkerhoff, K.M. Chan, A. Drozdetskiy, M. Hildreth, C. Jessop, D.J. Karmgard, N. Kellams, J. Kolb, K. Lannon, W. Luo, S. Lynch, N. Marinelli, D.M. Morse, T. Pearson, M. Planer, R. Ruchti, J. Slaunwhite, N. Valls, M. Wayne, M. Wolf, A. Woodard

The Ohio State University, Columbus, USA

L. Antonelli, B. Bylsma, L.S. Durkin, S. Flowers, C. Hill, R. Hughes, K. Kotov, T.Y. Ling, D. Puigh, M. Rodenburg, G. Smith, C. Vuosalo, B.L. Winer, H. Wolfe, H.W. Wulsin

Princeton University, Princeton, USA

E. Berry, P. Elmer, V. Halyo, P. Hebda, J. Hegeman, A. Hunt, P. Jindal, S.A. Koay, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, P. Piroué, X. Quan, A. Raval, H. Saka, D. Stickland, C. Tully, J.S. Werner, S.C. Zenz, A. Zuranski

University of Puerto Rico, Mayaguez, USA

E. Brownson, A. Lopez, H. Mendez, J.E. Ramirez Vargas

Purdue University, West Lafayette, USA

E. Alagoz, D. Benedetti, G. Bolla, D. Bortoletto, M. De Mattia, A. Everett, Z. Hu, M.K. Jha, M. Jones, K. Jung, M. Kress, N. Leonardo, D. Lopes Pegna, V. Maroussov, P. Merkel, D.H. Miller, N. Neumeister, B.C. Radburn-Smith, I. Shipsey, D. Silvers, A. Svyatkovskiy, F. Wang, W. Xie, L. Xu, H.D. Yoo, J. Zablocki, Y. Zheng

Purdue University Calumet, Hammond, USA

N. Parashar

Rice University, Houston, USA

A. Adair, B. Akgun, K.M. Ecklund, F.J.M. Geurts, W. Li, B. Michlin, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

University of Rochester, Rochester, USA

B. Betchart, A. Bodek, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, A. Garcia-Bellido, P. Goldenzweig, J. Han, A. Harel, D.C. Miner, G. Petrillo, D. Vishnevskiy, M. Zielinski

The Rockefeller University, New York, USA

A. Bhatti, R. Ciesielski, L. Demortier, K. Goulianos, G. Lungu, S. Malik, C. Mesropian

Rutgers, The State University of New Jersey, Piscataway, USA

S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Dugan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, A. Lath, S. Panwalkar, M. Park, R. Patel, V. Rekovic, J. Robles, S. Salur, S. Schnetzer, C. Seitz, S. Somalwar, R. Stone, S. Thomas, P. Thomassen, M. Walker

University of Tennessee, Knoxville, USA

K. Rose, S. Spanier, Z.C. Yang, A. York

Texas A&M University, College Station, USA

O. Bouhali⁶⁰, R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon⁶¹, V. Khotilovich, V. Krutelyov, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safonov, T. Sakuma, I. Suarez, A. Tatarinov, D. Toback

Texas Tech University, Lubbock, USA

N. Akchurin, C. Cowden, J. Damgov, C. Dragoiu, P.R. Duderod, J. Faulkner, K. Kovitangagoon, S. Kunori, S.W. Lee, T. Libeiro, I. Volobouev

Vanderbilt University, Nashville, USA

E. Appelt, A.G. Delannoy, S. Greene, A. Gurrola, W. Johns, C. Maguire, Y. Mao, A. Melo, M. Sharma, P. Sheldon, B. Snook, S. Tuo, J. Velkovska

University of Virginia, Charlottesville, USA

M.W. Arenton, S. Boutle, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, C. Lin, C. Neu, J. Wood

Wayne State University, Detroit, USA

S. Gollapinni, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane

University of Wisconsin, Madison, USA

D.A. Belknap, L. Borrello, D. Carlsmith, M. Cepeda, S. Dasu, S. Duric, E. Friis, M. Grothe, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, J. Klukas, A. Lanaro, A. Levine, R. Loveless, A. Mohapatra, I. Ojalvo, T. Perry, G.A. Pierro, G. Polese, I. Ross, A. Sakharov, T. Sarangi, A. Savin, W.H. Smith, N. Woods

†: Deceased

- 1: Also at Vienna University of Technology, Vienna, Austria
- 2: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
- 3: Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France
- 4: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
- 5: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
- 6: Also at Universidade Estadual de Campinas, Campinas, Brazil
- 7: Also at California Institute of Technology, Pasadena, USA
- 8: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
- 9: Also at Zewail City of Science and Technology, Zewail, Egypt
- 10: Also at Suez Canal University, Suez, Egypt
- 11: Also at British University in Egypt, Cairo, Egypt
- 12: Also at Cairo University, Cairo, Egypt
- 13: Also at Fayoum University, El-Fayoum, Egypt
- 14: Now at Ain Shams University, Cairo, Egypt
- 15: Also at Université de Haute Alsace, Mulhouse, France
- 16: Also at Joint Institute for Nuclear Research, Dubna, Russia
- 17: Also at Brandenburg University of Technology, Cottbus, Germany
- 18: Also at The University of Kansas, Lawrence, USA
- 19: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
- 20: Also at Eötvös Loránd University, Budapest, Hungary
- 21: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
- 22: Now at King Abdulaziz University, Jeddah, Saudi Arabia
- 23: Also at University of Visva-Bharati, Santiniketan, India
- 24: Also at University of Ruhuna, Matara, Sri Lanka
- 25: Also at Isfahan University of Technology, Isfahan, Iran
- 26: Also at Sharif University of Technology, Tehran, Iran
- 27: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
- 28: Also at Università degli Studi di Siena, Siena, Italy
- 29: Also at Centre National de la Recherche Scientifique (CNRS) - IN2P3, Paris, France
- 30: Also at Purdue University, West Lafayette, USA
- 31: Also at Universidad Michoacana de San Nicolas de Hidalgo, Morelia, Mexico
- 32: Also at National Centre for Nuclear Research, Swierk, Poland
- 33: Also at Institute for Nuclear Research, Moscow, Russia
- 34: Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia
- 35: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
- 36: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
- 37: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
- 38: Also at University of Athens, Athens, Greece
- 39: Also at Paul Scherrer Institut, Villigen, Switzerland
- 40: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
- 41: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
- 42: Also at Gaziosmanpasa University, Tokat, Turkey
- 43: Also at Adiyaman University, Adiyaman, Turkey
- 44: Also at Cag University, Mersin, Turkey

- 45: Also at Mersin University, Mersin, Turkey
- 46: Also at Izmir Institute of Technology, Izmir, Turkey
- 47: Also at Ozyegin University, Istanbul, Turkey
- 48: Also at Kafkas University, Kars, Turkey
- 49: Also at Istanbul University, Faculty of Science, Istanbul, Turkey
- 50: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
- 51: Also at Kahramanmaras Sütcü Imam University, Kahramanmaras, Turkey
- 52: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
- 53: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
- 54: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
- 55: Also at Utah Valley University, Orem, USA
- 56: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
- 57: Also at Argonne National Laboratory, Argonne, USA
- 58: Also at Erzincan University, Erzincan, Turkey
- 59: Also at Yildiz Technical University, Istanbul, Turkey
- 60: Also at Texas A&M University at Qatar, Doha, Qatar
- 61: Also at Kyungpook National University, Daegu, Korea